MODULE: 046
MANUFACTURING PROCESSES

ALUMINIUM


Materials
- Bauxite (the Ore).
- Sodium hydroxide.
- Cryolite

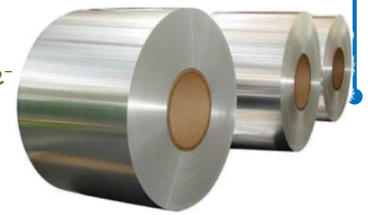
Process of extraction.
•Bauxite is ground into powder and heated in a steel container to convert any Iron (II) oxide impurity present into Iron (III) oxide and also to remove water of crystallization.
•The powder is then boiled with hot concentrated Sodium hydroxide solution that dissolves the amphoteric Aluminium oxide and acidic Silicon dioxide in the Ore forming Sodium aluminate and Sodium silicate in a container.

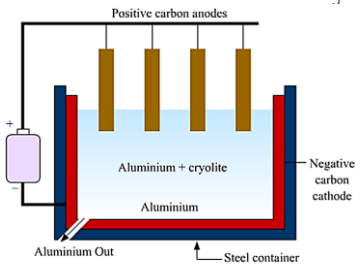
$$Al_2O_{3(s)} + 2NaOH_{(aq)} \rightarrow 2NaAlO_{2(aq)} + H_2O_{(l)}$$
$$SiO_{2(s)} + 3NaOH_{(aq)} \rightarrow Na_2SiO_{3(aq)} + H_2O_{(l)}$$

•The undissolved basic Iron (III) oxide is filtered off.
•Carbon dioxide is bubbled through the filtrate to precipitate Aluminium hydroxide leaving silicate ions in the solution.
•Aluminium hydroxide is washed, dried and strongly heated to produce Aluminium oxide.

Electrolysis of Aluminium Oxide.
- Aluminium oxide is placed in the electrolytic cell and heated with cryolite.
- Cryolite is used in the electrolysis of aluminium oxide for two main reasons: to lower the melting point of the mixture and to increase its conductivity.
- Molten aluminium oxide, Using graphite electrodes in an Iron bath lined with Graphite.

At the cathode; $Al^{3+}_{(l)} + 3e^- \rightarrow Al_{(l)}$
At the Anode; $2O^{2-}_{(l)} \rightarrow O_{2\,(g)} + 4e^-$





Extraction of aluminium

IRON

Materials:
- Iron ore (Heamatite)
- Coke.
- Limestone (calcium carbonate).

Process of extraction:
- Iron ore, coke and limestone are fed into the blast furnace from the top.
- Hot air is fed into the furnace from the bottom at about 1000 °C.
- Carbon (coke) is oxidized by hot air to carbon dioxide gas:

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

- Carbon dioxide gas produced is reacted with excess or unreacted coke producing carbon monoxide gas.

$$CO_{2(g)} + C_{(s)} \rightarrow 2CO_{(g)}$$

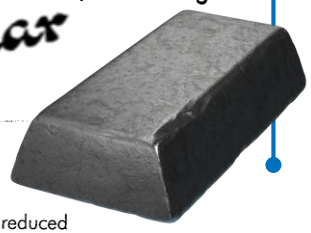
- The carbon monoxide produced reduces the Haematite to iron.

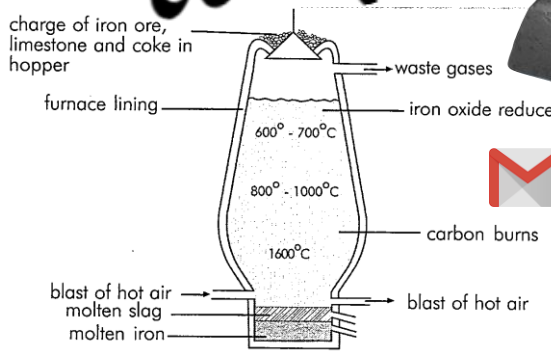
$$Fe_2O_{3(s)} + 3CO_{(g)} \rightarrow 2Fe_{(s)} + 3CO_{2(g)}$$

- Limestone decomposes to calcium oxide and carbon dioxide gas.

$$CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$$

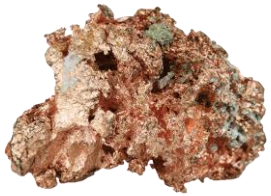
- The Calcium oxide combines with silica (Silicon dioxide) impurity to form slag (calcium silicate).
- The slag sinks to the bottom and floats on iron, protecting the iron from being re-oxidized hot air.
- **Purification:** Pure iron is obtained by passing air through molten iron to remove non-metal impurities.
- NOTE: Lime stone is used in the removal of impurities. E.g silicon dioxide (silica).





wanyamatitus47@gmail.com
+256-758496489

Copper




Materials
- Copper pyrites
- Silicon dioxide
- Oil
- Acidified copper(II) sulphate solution.

Process of extraction
a) **Concentration of the ore:**
The ore is crushed and ground to fine powder, mixed with oil and water in a steel tank to remove impurities.
- Compressed air is blown through the mixture in the tank a process known as froth flotation, to agitate the mixture.
- Oil coated particles of the ore float on top of the tank and are skimmed off and dried.

b) Reduction or roasting of the ore:
- Copper pyrites are roasted in a furnace to form copper(I) suphide, iron(II) oxide and Sulphur dioxide gas.

$$2CuFeS_{2(s)} + O_{2(g)} \rightarrow Cu_2S_{(s)} + 2FeO_{(s)} + 3SO_{2(g)}$$

- Silicon dioxide is added to the furnace. Where it reacts with iron(II) oxide to form iron(II) silicate, slag leaving behind the copper(I) sulphide.

The copper(I) sulphide is heated strongly in a furnace with limited supply of oxygen to form impure copper and Sulphur dioxide gas

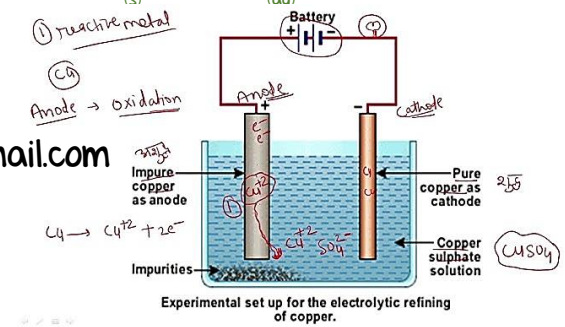
c) Purification:
The impure copper is purified by electrolysis using impure copper as anode and pure copper as cathode in an electrolyte cell containing acidified copper(II) sulphate solution as electrolyte.
- Impure copper dissolves to form copper(II) ions and pure copper is deposited at the cathode.

At the cathode, copper(II) ions are deposited as copper.

$$Cu^{2+}_{(aq)} + 2e^- \rightarrow Cu_{(s)}$$

At the anode, copper goes into solution as copper(II) ions.

$$Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2e^-$$



Experimental set up for the electrolytic refining of copper.

CEMENT

Materials
- Limestone
- Clay, shale
- Silica
- Iron oxide

Process Of Production
- The raw materials are run through a crusher and milled into fine powder.
- The powders are blended and pre-heated to around 900°C in a rotary kiln using hot gases. The pre-heating burns off impurities.
- The material is burnt in a large rotary kiln at 1500 °C.
- The rotary kiln continuously mixes the ingredients and distributes heat uniformly on limestone to decompose it to Calcium oxide so that carbon dioxide is driven off, forming clinker.

$$CaCO_{3\,(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$$

- The clinker is then cooled and ground to a fine powder in a rotating drum filled with steel balls of different sizes - depending on the desired fineness of the cement, that crush and grind the clinker.
- Gypsum is added during the grinding process to moderate or control the 'setting' of the cement.
- The cement is then bagged ready for sale, transportation and use.

CHLORINE GAS

Raw material
Concentrated sodium hydroxide solution (brine).
Graphite.
Mercury.

Process Of Production
- Brine is electrolyzed in an electrolytic cell having graphite anode and mercury cathode.
- During the electrolysis, chloride and hydroxide ions migrate to the anode.
- Chloride ions are preferentially discharged by electron loss to form chlorine gas due to their high concentration.
- At the Anode: $2Cl^-_{(aq)} \rightarrow Cl_{2\,(g)} + 2e$
- The chlorine formed is dried, liquefied and stored in tightly closed tanks.

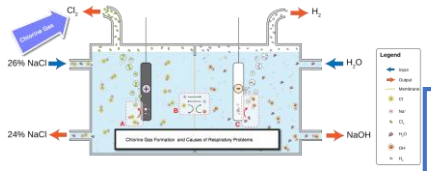
SODIUM HYDROXIDE

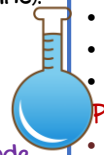
Materials
- Concentrated sodium hydroxide solution (brine).
- Graphite.
- Mercury.

Process Of Production
- Brine is electrolyzed in an electrolytic cell having graphite anode and mercury cathode.
- During the electrolysis, Sodium ions and hydrogen ions migrate to the cathode.
- Due to high concentration of sodium hydroxide, sodium ions are discharged in preference to hydrogen ions by electron gain to form sodium metal.
- Cathode (negative electrode): mercury flowing along bottom of cell

$$Na^+_{(aq)} + e^- \rightarrow Na_{(s)}$$

- The sodium metal dissolves (combines with) in mercury to form sodium amalgam which is reacted (dissolved in) with water to form sodium hydroxide solution, hydrogen and mercury. Mercury is fed back into the cell for re-use as the cathode.
- The sodium hydroxide solution is evaporated to dryness to molten sodium hydroxide and cooled to form solid sodium hydroxide.





SULPHURIC ACID

Raw materials
- Sulphur.
- Oxygen.
- Vanadium(v) oxide.
- Water.

Process of production.
- Sulphur is heated strongly or roasted in a closed cylinder to produce Sulphur dioxide gas.
  - $S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$
- Sulphur dioxide is further reacted with excess oxygen in presence of vanadium(v) oxide catalyst at 400 °C- 500 °C and 1-2 atmospheres in a closed cylinder to produced sulphur trioxide gas.
  - $2SO_{2(g)} + O_{2(g)} \rightarrow 2SO_{3(g)}$
- Sulphur trioxide gas is bubbled in a tank containing concentrated sulphuric acid to form oleum.
- Oleum is diluted with appropriate volume of water to produce sulphuric acid which is stored in storage tanks.

$$2SO_{3(g)} + H_2SO_{4(aq)} \rightarrow H_2S_2O_{7(l)}$$
$$H_2S_2O_{7(l)} + H_2O_{(l)} \rightarrow H_2SO_{4(l)}$$

- The sulphuric acid is then stored in the storage tanks.

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LIME
- Limestone is grounded into fine particles, then fed into a kiln, heated at about 900°C to form quick lime.
- $CaCO_{3(s)} \rightarrow CaO(s) + CO_{2(g)}$
- The quick lime (calcium oxide) formed is then cooled, added to water forming slake lime (Calcium hydroxide) in a sealed reactor tank.
- $CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(aq)}$
- The slake lime formed is passed through the purifiers to remove any impurities and water, concentrated and packed.

OXYGEN

Materials
- Air.
- Silica gel.
- Concentrated sodium hydroxide solution.

Process of production
- Air is passed through filters to remove smoke particles and dust particles.
- Air is passed through concentrated sodium hydroxide solution to absorb/ remove carbon dioxide, which is acidic.
  - $2NaOH_{(aq)} + CO_{2\,(g)} \rightarrow Na_2CO_{3\,(aq)} + H_2O_{(l)}$
- Air is free from Carbon dioxide is now passed through Silicon(IV) oxide (silica gel) to absorb water vapour.
- Carbon dioxide and water vapour are removed from air before it is liquefied because they solidify and block the apparatus.
- The air is now compressed at 200 atmospheres and allowed to cool by making it escape into a large space through a jet.
- The process of cooling is repeated several times to obtain liquid air at about -200°C.
- The liquid air is fractionally distilled using a fractionating column.
- Nitrogen boils off first because it has a lower boiling point (-196°C) leaving behind oxygen with a higher boiling point (-183°C).
- Both nitrogen and oxygen collected obtained contain traces of noble gases.
- Pure oxygen is then stored under pressure in steel cylinders.

wanyamatitus47@gmail.com
+256-758496489

FERTILIZERS

AMMONIA

Raw materials.
- Nitrogen gas
- Hydrogen gas.

Process of production
- Nitrogen gas from fractional distillation of liquid air is reacted with hydrogen gas from natural gas in a ratio of 1:3 respectively. This is done in a closed cylinder, at temperature (450 – 500 °C), and pressure of 200 atmospheres, with a finely divided Iron Catalyst.

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$

Anhydrous ammonia is stored as a liquid under pressure for ease handling in cyliders.

Bio Gas

- Biogas can be made from agricultural waste, manure, sewage, food scraps, and plant material.
- The waste is crushed and mixed with water to form a slurry.
- The slurry is placed in an anaerobic digester, a sealed container where bacteria break down the organic matter..
- The bacteria produce methane (CH_4) and carbon dioxide (CO_2) as the main gases.Other gases like hydrogen sulfide (H_2S) may also be present.
- The biogas is collected in a gas storage chamber.
- Impurities like water vapor and hydrogen sulfide are removed to improve quality.
- The purified biogas can be used for cooking, heating, electricity generation, or even as vehicle fuel.The leftover material (digestate) is used as organic fertilizer.

AMMONIUM NITRATE

- Ammonium nitrate fertilizer is obtained from nitric acid and ammonia gas.
- During Haber process:
- Nitrogen obtained from air reacts with hydrogen from natural gas in a sealed container at 450°C and 200 atmospheres to form ammonia gas.
- The gas is then purified, liquefied and refrigerated.
  - $N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$
- During Catalytic Oxidation of ammonia: ammonia gas is oxidized to nitric oxide gas in a sealed container in the presence of platinum – rhodium catalyst.
- The nitric oxide gas then reacts with water to form Nitric acid.
  - $3NO_{2(g)} + H_2O_{(l)}\ 2HNO_{3(aq)} + NO_{(g)}$
- Both nitric acid and ammonia gas are heated in a neutralizer reactor tank to form ammonium nitrate as fertilizer, purified, concentrated and packed.
  - $NH_{3(g)} + HNO_{3(aq)} \rightarrow NH_4NO_{3(s)}$

UREA FERTILIZER

- Urea fertilizer is obtained from ammonia and carbon dioxide gas.
- During Haber process: nitrogen obtained from air with hydrogen from natural gas in a sealed container at temperatures of 450°C and pressure of 200 atmospheres to form ammonia gas.
- Ammonia gas is then purified, liquefied and refrigerated.

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$$

- Both ammonia gas and carbon dioxide gas react in a sealed reactor tank to form Urea as fertilizer, purified, concentrated and packed.
- $2NH_{3(g)} + CO_{2(g)} \rightarrow H2NCONH_{2(s)} + H2O_{(l)}$

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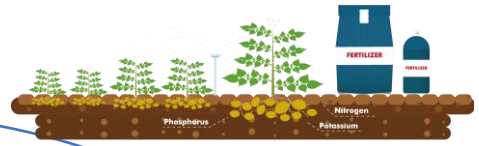


AMMONIUM SULPHATE FERTILIZER

- Ammonium sulphate fertilizer is obtained from Sulphuric acid and ammonia gas.
- During Haber process:
- Ammonia is produced by reacting nitrogen obtained from air with hydrogen from natural gas in a sealed container at temperatures of 450°C and pressure of 200 atmospheres forming dry ammonia gas.
- The gas is then compressed into liquid and refrigerated.

$$N_{2(g)} + 3H_{2(g)}\ 2NH_{3(g)}$$

- During Contact process: Sulphuric acid is produced by reacting sulphur in air to form sulphur dioxide gas; followed by catalytic oxidation of sulphur dioxide to form sulphur trioxide gas in a sealed reactor tank.

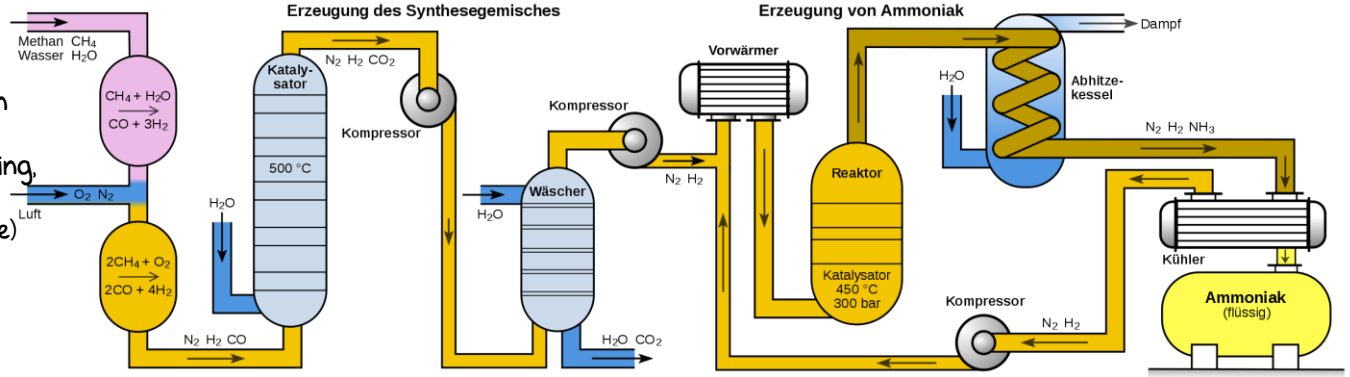
$$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$$
$$SO_{2(g)} + O_{2(g)} \rightarrow SO_{3(g)}$$

- The sulphur trioxide gas formed is then reacted in a sealed reactor tank containing concentrated Sulphuric acid to form Oleum, which is dissolved in water to form pure Sulphuric acid.

$$SO_{3(g)} + H_2SO_{4(L)} \rightarrow H_2S_2O_{7(L)}\ (Oleum)$$
$$H_2S_2O_{7(L)} + H_2O_{(l)} \rightarrow 2H_2SO_{4(aq)}$$

- Both Sulphuric acid and ammonia gas are heated in a sealed reactor tank to form ammonium sulphate as fertilizer, purified, concentrated and packed.

$$2NH_{3(g)} + H_2SO_{4(aq)} \rightarrow (NH_4)_2SO_{4(s)}$$



wanyamatitus47@gmail.com
+256-758496489

ETHANOL

From Bananas

Raw material: bananas, sorghum, water

Process of production

- The bananas are covered after harvesting for about a week to ripen. (During Ripening, enzyme diastase convert the starch in banana to maltose).

$$Starch + H_2O_{(l)} \rightarrow C_{12}H_{22}O_{11(aq)}$$

- The ripe bananas are put in a wooden trough and then squeezed between spear grass to extract the juice from them while adding water.
- The mixture is filtered to obtain juice.

- Sorghum which has been roasted is added to the filtered juice and the mixture is stored.
- The mixture is then covered in a warm place to cut off oxygen supply to allow fermentation to occur.
- Yeast from fermented sorghum provides maltase enzyme which catalyses hydrolysis of maltose to glucose.

$$C_{12}H_{22}O_{11(aq)} + H_2O_{(l)} \rightarrow 2C_6H_{12}O_{6(aq)}$$

- Zymase enzyme from yeast catalyses the hydrolysis of glucose to ethanol which is crude

$$C_6H_{12}O_{6(aq)} \rightarrow 2C_2H_5OH_{(l)} + 2CO_{2(g)} + Heat$$

- The crude ethanol is purified by fractional distillation to obtain pure ethanol.

Soapless Detergents

Benzene is reacted with a long chain alkene in presence of an acid to form alkylbenzene.
The alkylbenzene is heated with concentrated sulphuric acid to form alkylbenzene sulphonic acid, which is then neutralised by heating it with concentrated sodium hydroxide to form Sodium alkyl benzene sulphonate, the soapless detergent.

Alkyl benzene sulphonic acid + NaOH → Sodium alkyl benzene sulphonate + H_2O

Examples of soapless detergents include;

- Sodium Lauryl Sulphate,
- Sodium Laureth Sulphate,
- Ammonium Lauryl sulphate,
- Linear alkylbenzene sulphonate.

From Cassava

- Cassava is ground in a mortar and mixed with water to form starch solution in a steel container.
- Malt is added to starch solution, and diastase enzyme in malt hydrolyses starch to maltose.

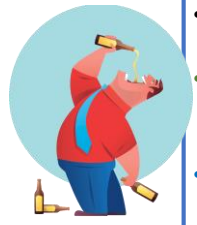
$$Starch + H_2O_{(l)} \rightarrow C_{12}H_{22}O_{11(aq)}$$

- Yeast is then added to the mixture.
- Yeast contains two enzymes, maltase and zymase.
- Maltase catalyses the hydrolysis of maltose to glucose as below.

$$C_{12}H_{22}O_{11(aq)} + H_2O_{(l)} \rightarrow 2C_6H_{12}O_{6(aq)}$$

- Zymase catalyses the breakdown of glucose into ethanol, carbon dioxide, producing heat in the process.

$$C_6H_{12}O_{6(aq)} \rightarrow 2C_2H_5OH_{(l)} + 2CO_{2(g)} + Heat$$



Soapy Detergents

MATERIALS:

- ✓Vegetable oil
- ✓Sodium hydroxide solution
- ✓Concentrated sodium chloride solution

Process of production

- Vegetable oil is first bleached with animal charcoal.
- Vegetable oil is boiled with sodium hydroxide solution for sometime until frothing stops.
- The mixture is left to cool.

(The ester in the vegetable oil breaks down releasing the organic acid and an alcohol, a process called saponification.
The organic acid is immediately neutralized by sodium hydroxide solution to form a sodium salt of the organic acid, which is the soap.)

- The soap is precipitated by addition of concentrated sodium chloride solution, a process called 'salting out'.
- Sodium chloride lowers the solubility of soap and causes precipitation of soap which floats on top of the solution.
- The solid soap is then removed and compressed into a continuous block which is cut into bars.

Examples of soapy detergent: Sodium stearate, Potassium stearate, Sodium oleate, Potassium oleate, Sodium palmitate, Potassium palmitate

From Sorghum or Millet

- Sorghum is ground in a mortar and mixed with little water to form a paste.
- The sorghum paste is buried underground and left for a week to ferment to form yeast,
- Fermented sorghum is removed from underground and sun dried.
- And them mixed with ground Germinating sorghum (containing maltose) in a plastic drum with warm water.
- The plastic drum is covered with air tight lid, and left to stand for about 3 to 5 days.
- Maltase enzyme in yeast catalyse the hydrolysis of Maltose to glucose.

$$C_{12}H_{22}O_{11(aq)} + H_2O_{(l)} \rightarrow 2C_6H_{12}O_{6(aq)}$$

- Then another enzyme from yeast called Zymase catalyses the hydrolysis of glucose to ethanol which is crude ethanol.

$$C_6H_{12}O_{6(aq)} \rightarrow 2C_2H_5OH_{(l)} + 2CO_{2(g)} + Heat$$

- Pure ethanol can be purified by fractional distillation of crude ethanol.

Wanyermax

wanyamatitus47@gmail.com

+256-758496489